IMPROVEMENT OF ADVANCING FRONT MESH METHOD IN TRIANGLE HOLE FILLING

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

July 2022

FSKTM 2022 28

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Mesh-based or triangulated prototypes are widely used to represent objects in many modelling and computer-aided engineering applications. In certain cases, there is a possibility of missing points when scanning devices fail to enter certain regions; and those area captured as a hole in the scanning process. These holes need to be filled in order to develop an error-free triangulated prototype. The Advancing Front Mesh method is used to fill a triangle to overcome this problem. This method iteratively meshes a hole's area by inserting new triangles and nodes at the hole's boundary, then moves to the inside of the area until it is closed. However, problems occur when finding new points using this method. In this research, an improved Advancing Front Mesh method is proposed to solve the problem of filling holes when encounter three intersection problem for the triangular mesh. The first problem is that when a new generated point is unconnected to any active point, using the usual threshold circle. Thus the intersection point was calculated between the threshold circle to any line segment in a triangle in order to check for nearest active point. Secondly, the triangle created overlaps other triangles; the circumcircle surrounded all the starting points along with the new points was used to check for any extra active point. Then the magnitude was calculated between previous new point to the new active point to identify the correct points. Thirdly, when the new generated point is close to the hole's boundary, the threshold radius have been enlarged in order to find the new point. Then the bisection point was calculated if there is no active point in the enlarged radius. The first validation is carried out using the interpolating surface of the test data with three familiar bivariate functions. Meanwhile, the second "visual similarity" validation is carried out using a questionnaire to compare the experimental outcome with the original figure. The results of this research contribute to the method of satisfying an object's visualization and provides an enhanced method of AFM for filling a hole in triangular mesh.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENAMBAHBAIKAN KAEDAH JARINGAN DEPAN DALAM PENGISIAN LUBANG SEGITIGA

Oleh

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Prototaip berasaskan jejaring atau triangulasi digunakan secara meluas untuk mewakili objek dalam banyak pemodelan dan aplikasi kejuruteraan berbantukan komputer. Dalam kes tertentu, terdapat kemungkinan titik hilang apabila peranti pengimbasan gagal memasuki kawasan tertentu; dan kawasan tersebut ditangkap sebagai lubang dalam proses pengimbasan. Lubang-lubang ini perlu diisi untuk membangunkan prototaip triangulasi bebas ralat. Kaedah Advancing Front Mesh digunakan untuk mengisi segitiga bagi mengatasi masalah ini. Kaedah ini secara berulang menyatukan kawasan lubang dengan memasukkan segitiga dan nod baharu pada sempadan lubang, kemudian bergerak ke bahagian dalam kawasan itu sehingga ia ditutup. Walau bagaimanapun, masalah berlaku apabila mencari titik baharu menggunakan kaedah ini. Dalam penyelidikan ini, kaedah jaringan hadapan yang ditambah baik dicadangkan untuk menyelesaikan masalah mengisi lubang apabila menghadapi masalah tiga persimpangan bagi jaringan segi tiga. Masalah pertama ialah apabila titik terjana baharu tidak disambungkan ke mana-mana titik aktif, menggunakan bulatan ambang biasa. Oleh itu, titik persilangan dikira antara bulatan ambang ke mana-mana segmen garisan dalam segi tiga untuk menyemak titik aktif yang terdekat. Kedua, segitiga yang dicipta bertindih dengan segitiga lain; bulatan mengelilingi semua titik permulaan bersama-sama dengan titik baharu digunakan untuk memeriksa sebarang titik aktif tambahan. Kemudian magnitud dikira antara titik baru sebelum ini ke titik aktif baru untuk mengenal pasti titik yang betul. Ketiga, apabila titik yang dijana baharu hampir dengan sempadan lubang, jejari ambang telah diperbesarkan untuk mencari titik baharu. Kemudian titik dua belah dikira jika tiada titik aktif dalam jejari yang diperbesarkan. Pengesahan pertama dijalankan menggunakan permukaan interpolasi data ujian dengan tiga fungsi bivariat biasa. Sementara itu, pengesahan "persamaan visual" kedua dijalankan menggunakan soal selidik untuk membandingkan hasil eksperimen dengan angka asal. Hasil penyelidikan ini menyumbang kepada kaedah memuaskan visualisasi objek dan menyediakan kaedah AFM yang dipertingkatkan untuk mengisi lubang dalam jaringan segi tiga.

ACKNOWLEDGEMENTS

A special thanks to my main supervisor, Professor Rahmita Wirza O.K Rahmat, co-supervisors, Associate Professor Dr. Azmi Jaafar, Associate Professor Dr. Puteri Suhaiza Sulaiman and Dr. Ng Seng Beng for their advice and support that led me throughout the research and thesis writing process. Thank you also for my family and friends who help me during hard times and happiness. Thank you for being there during my journey to finish my PHD.

Last but not least, I would like to thank all lecturers and support staff from the Faculty of Computer Science and Information Technology which given help directly or indirectly toward the completion of this thesis.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AFM	Advancing Front Mesh
CAD	Computer Aided Design
CAGD	Computer Aided Geometric Design
CMM	Coordinate Measurement Machine
CNC	Computer Numerical Control
DT	Delaunay Triangulation
EAFM	Enhanced Advancing Front Mesh
FIS	Fuzzy Inference System
LBF	Loopy Belief Propagation
MAFM	Modified Advancing Front Mesh
MC	Marching Cube
MRF	Markov Random Fields
PDE	Partial Differential Equation
RBF	Radial Basis Function
UAV	Unmanned Aerial Vehicles

CHAPTER 1

INTRODUCTION

1.1 Background of research

Reverse engineering is a model that transforms the existing product model or physical model into an engineering design model or conceptual model. With the development and application of computer technology especially the theories and techniques of computer aided geometric design, reverse engineering has become an important means to obtain three-dimensional model. Reverse engineering including data acquisition, data processing and surface reconstruction. Undoubtedly, the triangle mesh model has become the popular representation for 3D geometry modelling. It has been widely applied in the fields of Computer Graphics and CAD.

Three dimensional (3D) optical scanning devices can be used to capture the surface model of damaged parts in the form of a 3D point cloud with the use of computer vision and digital image processing technology. The measured 3D point cloud is frequently incomplete, resulting in numerous holes after the point cloud triangulation, due to the self-contained constraints of 3D scanning technologies and the occlusion between the physical item and the utilized scanner. This limitation caused those certain materials cannot be digitized. Some parts of the object may be missing or some local data of the mesh model may be lost due to the limitation of the quality of the scanning equipment.

The presence of holes in the mesh reduces the performance of downstream mesh processing algorithms, such as mesh alignment and Boolean operations, potentially leading to processing failure. Incomplete triangular meshes, on the other hand, may result in poor visualization effects. These holes influence many mesh operations and a mesh model with holes cannot be directly utilized by applications. Consequently, we have to fill and repair them in advance to obtain a whole mesh model of the object.

1.2 Problem statement

In the disciplines of mechanical manufacturing, emergency rescuing, biomedical engineering, and other fields, additive manufacturing repair has been widely employed to extend the lifespan of damaged parts as a typical cost-saving, digital, and intelligent manufacturing approach. However, with the rapid advancement of printing and scanning technologies, traditional manual repair is becoming increasingly time-consuming and labor-intensive, as well as producing uneven quality. It is critical to have a system that can automatically fix damaged parts (Tabib et al., 2020).

3D scanning devices can employ either ‘object in touch’ (contact) or other approaches, where touching is not present (non-contact). Because of their high scanning speed, real-time applications, high precision, etc., non-contact methods are deemed more useful. As most 3D objects have complex geometries, contact methods are less required than non-contact techniques. New techniques to digitalize 3D objects include non-contact laser scanning, which allow 3D Computer Aided Design (CAD) frameworks to be created for objects with highly complex surfaces. The results of optical flow were used in this research for implementation. Optical flow was used to detect object movement between set of images where the displacement is able to provide information about an object relative to the observer's distance. Optical flow can be used to evaluate the depth value of that point and 3D point of the object can be achieved if a successful feature tracker is able to identify the matching feature point in the subsequent image or frame (Beng, 2015).

This approach exposes a missing point that creates a void in the region where the paint is white, shiny and glossy. The presence of undesired holes impacts the model's visualization, and can lead to unexpected results for the application; such as segmentation, rapid prototyping, and analysis of finite elements. A technique known as the Advancing Front Mesh (AFM) method was used to patch a triangle in a hole by adding new elements and nodes at the boundaries (referred to as the front) of an area; thus, iteratively meshing the area. One of the advantages of AFM is that the creation of a new triangle is co-instantaneous with the generation of a new node. The front then travels to the inside of the region until it closes. This benefits the ability to regulate the element's size and shape by changing the position of the node (Zhao, 2007; Agarwal and Agrawal, 2019; Feng, 2020).

However, there is a situation where conflict arises in the filling of hole and the AFM approach needs to be strengthened to solve problems with holes. If the original method cannot find the new point, the approach must be changed to address this issue. Furthermore, several AFM system implementations exist in handling triangle overlapping problems and discovering new points near the boundary of holes.

Problem of 3D object with missing holes on triangular mesh leading to the following **PROBLEM STATEMENT** for this research:

a) no existing active point inside the identified threshold circle, thus there is a need to approximate and locate the position of a new point.

b) approximation point created overlaps another triangular patches therefore the approximate point needs to reposition.

c) point falls near the boundary of holes and not connected to any active points, thus to avoid skinny triangle the approximate point need to reposition.

1.3 Objective of research

The main aim of this work is to establish a procedure to approximate triangular patches into a hole. To achieve this aim, these are the objective that needs to fulfill:

a) To introduce a new method on how to locate the approximation point when they are **no active point inside the threshold circle.**

b) To propose a new approach on how to select candidate for approximate point when **the point created overlaps another triangle**.

c) To construct a new algorithm **to avoid skinny triangle.**

1.4 Scope and limitation of research

Point cloud has become one of the most significant data formats for 3D representation. The general issues in point cloud distribution are irregularity, unstructured, and unorderness grid make the object difficult to model. The object chosen as a scope in this research was having irregularity characteristic as in research by Bello et al. (2020).

Irregularity: Point cloud data is irregular, meaning, the points are not evenly sampled across the different regions of an object/scene, so some regions could have dense points while others sparse points.

The scope of the study are four optical flow subject data, which **cover front and back views**. This gives a total of **8 subjects** under consideration for this research. The data points were obtained from optical flow research by (Beng, 2015). The data points can be divided into three types of holes, the normal holes, the overlap triangle hole and the holes near the boundary. Limitation of the data is only to the object which already have a presence of holes due to the scanning process. Thus, the data point was enough to use to solve the hole filling problems on triangle mesh. Furthermore, **the 36 test data points** Whelan T. (1986); Renka and Cline (1984) was used throughout each chapter for validation process.

MATLAB R2016a software was used to program all the techniques and display of figures in this research. The device use was Acer Laptop with processor of Intel(R) Core(TM) i3-8145U, CPU @ 2.10GHz 2.30 GHz, Installed RA 4.00 GB and system type of 64-bit operating system, x64-based processor.

1.5 Significance of research

The problem of missing point was due to an error during scanning and it weakening of both the visual effects of a 3D model and its post-processing performance. The three contribution listed in this study able to enhance the method of advancing front mesh method in solving different type of problems during holes filling. Thus, the process of hole filling will be faster and able to produce better 3D visualization result.

1.6 Thesis organization

The thesis is composed of seven chapters including Chapter 1 which mentioned as the introductory chapter. It begins with a background of research and applications analysis. In addition, the problem statement, research objective, scope and limitation of research and the significance of research are explained in this section.

Chapter 2 explains the previous and associated work on the 3D scanning devices, pre-processing technique, the holes filling, AFM-based hole filling techniques and smooth surface reconstruction.

Chapter 3 describes the research methodology and research framework, data acquisition, experiment subject, advancing front mesh used in the research and smooth surface reconstruction which used in validation method.

Chapter 4 describes the all the proposed method of enhanced AFM method. The chapter begins with preprocessing of the proposed algorithm technique and the process of finding holes by AFM method. The proposed method was explained in subtopic 4.3, 4.4 and 4.5. Each subtopic begins with an introduction, the suggested algorithm approach, implementation, findings and discussion and triangle outcome analysis.

Chapter 5 resolved the result and discussion chapter which explained on three validation method. Firstly, validation was the skewness of triangle mesh was calculated and compared with the result from previous researcher on the same method. Secondly the validation was using the test data where all the three problem was encounter. Third validation was visual evaluation via a questionnaire form which was known as a subjective visual similarity assessment.

Finally, in Chapter 6, **t**his final chapter concludes the study, highlights the contributions and also provides an overall review of the proposed approach and recommends suggestions for future work.

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